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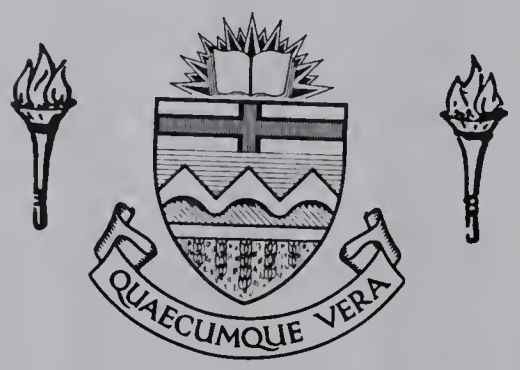

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CHEMICAL CONTROL OF CIRSIUM ARVENSE (L.) SCOP. AND SONCHUS ARVENSIS L. IN RELATION TO ECOLOGY OF SALINE LAKE-SHORE VEGETATION

BY

© R. K. GUPTA

A DISSERTATION

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR

THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF PLANT SCIENCE

EDMONTON, ALBERTA

NOVEMBER, 1968

Thesis
1969
53

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Chemical Control of Cirsium arvense (L.) Scop. and Sonchus arvensis L. in Relation to Ecology of Saline Lake-shore Vegetation" submitted by R. K. Gupta in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

In saline areas bordering Miquelon Lake, a water-fowl refuge, it was possible to maintain tall vegetative cover of Cirsium arvense L. Scop. (Canada thistle) and Sonchus arvensis L. (perennial sow thistle) while preventing their flowering and seed dispersal, by means of small dosages of 4-amino-3,5,6-trichloropicolinic acid (picloram) or of 2,4-dichlorophenoxyacetic acid (2,4-D) applied before the thistles flowered. Picloram sprays at a dosage as small as 0.25 oz/A prevented flowering of Canada thistle treated in early bud stage. For comparable results with perennial sow thistle which was somewhat more resistant to small dosages of picloram this treatment had to be applied just prior to the plants' early bud stage. Results comparable to those noted for picloram were achieved with 8 oz/A of 2,4-D.

For complete prevention of flowering of both species of thistles treated at late bud stage, picloram at 1.5 oz/A or 2,4-D at 2 lb/A was necessary. However, these higher dosages also caused extensive damage to the vegetative top growth of the thistles.

In other experiments with a dense stand of Canada thistle growing on cultivated fertile clay loam soil the objective was to study techniques of eradication of the thistles. Best results were obtained by mowing the weeds at their flowering stage and spraying their regrowth about a month later with 4 oz/A picloram, followed by a second treatment of regrowth with 2 oz/A picloram, after comparable mowing of the surviving thistles during the following year. This practice was more effective than those where no mowing was included, involving either spraying thistles at flowering stage or spraying half dosage of herbicide at flowering stage and half in the fall. Both with regard to reduction in numbers of new shoots and of their total mass two years after the

first treatment, effects of as little as 2 oz/A of picloram were greater than those resulting from use of 2 lb/A 2,4-D ester in any of the procedures noted.

At Miquelon Lake where Hordeum jubatum L. (foxtail barley) was a dominant native component of the vegetation of the saline experimental areas, Canada thistle and perennial sow thistle top growth and regrowth were eliminated for at least two years duration of observations by single spray treatments with picloram at 4-6 oz/A. These resulted in an increase in cover of the native grass species associated with a decline or disappearance of some of the low-growing native dicotyledonous species present in some plots.

2-Methoxy-3,6-dichlorobenzoic acid (dicamba) applied at 6 to 24 oz/A and 2,4-D ethyl ester at 24 to 96 oz/A were incapable of complete supression of regrowth from roots of treated thistles. Treatments with as little as 1 oz/A of picloram resulted in 90% reduction in stand of the thistles within a year in plots having foxtail barley and other grasses as competitors able to fill in the cover.

Ground sprayer applications of herbicide produced more uniform results than aerial spraying of narrow strips of thistle-infested land.

From the agricultural standpoint complete eradication of the thistles would be the simplest procedure in this area where natural plant succession is towards salt-tolerant grasses. From a wildlife management viewpoint it is difficult to know, whether merely preventing flowering of thistles or removing them altogether would make any important difference insofar as strips of farmland shore line are concerned.

ACKNOWLEDGEMENTS

I wish to express my deep sense of gratitude to Dr. Wm. G. Corns for his valuable guidance and encouragement during the course of my research program and for helpful suggestions in the preparation of this manuscript. The excellent assistance of Mr. R. J. Schraa with preparation of illustrative material is gratefully acknowledged.

I also wish to express my appreciation for financial assistance received from the Alberta Agricultural Research Trust and I thank the Department of Plant Science for the use of equipment and facilities.

It is also a pleasure to acknowledge the contribution of picloram supplies by Dow Chemical Company and the cooperation of Mr. E. A. Havlick and the County of Camrose who arranged for experimental aerial spraying at Miquelon Lake.

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INTRODUCTION

Motivation for the research which was the basis of this thesis came from problems concerned with control of perennial weeds on land bordering Miquelon Lake, a bird sanctuary, located about twenty miles north of Camrose and about forty miles south east of Edmonton, Alberta (Township 49, Range 21, West of the 4th Meridian). Several low lying saline areas (48) along the lakeshore where foxtail barley (Hordeum jubatum L.) is the dominant species, have for many years been infested with the noxious perennials Canada thistle (Cirsium arvense (L.) Scop.) and perennial sow thistle (Sonchus arvensis L.). Their windborne seeds can increase weed control problems on adjacent and more remote cultivated farm lands.

Announcement of plans in 1965 by Camrose municipal officials to spray the selective herbicide 2,4-D from aircraft along the weed-infested lakeshore caused concern among some regional wildlife scientists and officers about removal of the weed cover, spray drift and toxicity to desirable organisms. Consequently there was a series of discussions involving interested governmental, municipal and University of Alberta personnel. There was agreement that appropriate experimental plot work should precede any large scale use of herbicides at Miquelon Lake. The Department of Plant Science, University of Alberta, agreed to undertake responsibility for research on vegetation control and for liaison with other interested personnel. Land for experiments at the west end of Miquelon Lake (N.E. 26, 49, 21, 4) was made available to the university through kindness of the owner Mr. F. R. Wall.

The objective was to study the feasibility of safe use of herbicidal or other methods to control the weeds while trying to maintain a suitable habitat or to establish improved cover for the water-fowl and

associated creatures. Accordingly the study was divided into two related parts, one dealing with the introduction of potential crops and their responses to herbicidal treatments and to other management practices as described by Rahman (48) and the other part emphasizing aspects of weed control as reported herein. This work involved comparisons of the efficiency of certain selective herbicides for vegetation control, techniques of their application and observations regarding spray drift. Emphasis on the one hand was placed on efforts to determine satisfactory ways to eliminate the thistles and on effects of their removal upon natural replacement vegetation. On the other hand it was also of interest to study means of simply preventing seed production of the thistles without killing their vegetative cover. This might be an alternative acceptable procedure if it were not feasible to eradicate the thistles.

In addition to the field experiments at Miquelon Lake supplementary field studies on fertile black clay loam soil were conducted at Ellerslie, near Edmonton, together with related greenhouse studies in the Plant Science Department at the University of Alberta.

LITERATURE REVIEW

General characteristics of Canada thistle and perennial sow thistle

Canada thistle and perennial sow thistle are widely distributed in Canada (17). The Canada thistle involved in this study was Cirsium arvense (L.) Scop. which typically has spiny leaves and stems and creeping underground roots (46). There are at least two varieties in western Canada (17, 45). The spininess, indentation and surface characteristics of the leaves are major features distinguishing the common spiny form from the smooth leaf form. Canada thistle is perennial and dioecious (14) and reproduces both vegetatively and from seeds. Root pieces as small as 1/8 to 1/4 inch in diameter and 1/4 to 1/2 inch in length which possess a bud can produce new plants (47). Heads of Canada thistle, open for 11 days or longer, produce a high percentage of viable seeds (14). Pennington (46) reported that 10 patches of female thistles in northern Idaho harvested each year for three years 1963 to 1965, produced seed yields ranging from 82 to 788 lbs of seed per acre. The germination of these seeds varied widely from year to year. The average after-harvest germination for the samples taken in 1963, 1964, and 1965 respectively, was 70, 10 and 7 per cent. In determinations of the number of seeds per pound, Hodgson (30) found that it ranged from 300,000 to 673,000. He reported the existence of imperfect dioeciousness in this species as indicated by the production of an occasional viable seed by bagged staminate flowers.

Like Canada thistle, perennial sow thistle (Sonchus arvensis L.) spreads by means of seeds and horizontal roots, and it differs from Canada thistle in having perfect flowers (17, 45, 54). Both species however are cross-pollinated (14) and their seeds produce copious amounts of pappus which facilitates widespread dissemination by wind.

Control methods

In controlling spread of thistles it is necessary to prevent seed formation and to destroy the underground parts (44). Control may require either cultural or chemical means or a combination of both methods.

Chemical prevention of flower production

On account of wide dispersal of seed by the wind the prevention of seed production is especially important. According to Derscheid et al. (15) 2 lb/A amitrol consistently prevented the production of seeds in these species when applied at their bud stage. Similarly 2 and 4 lb/A of 4-(2,4-DB) prevented seed production of Canada and perennial sow thistle treated at the spring rosette stage. Friesen (20) reported that the application of picloram at a dosage of 1.5 oz/A or more when thistles had 4-5 leaves inhibited vegetative growth and prevented flowering throughout the season. However there appear to have been no studies where the primary objective was simply to prevent flower production and have minimal effect on vegetative growth.

Cultural and chemical control of vegetative growth

Before the use of modern herbicides, cultural and cropping practices were the only means available for the control of these species. By frequent mowing, starting in early June and continuing monthly at least through August, Canada thistle could be eradicated within 4 years (62). The work of Arny (5) showed that readily available carbohydrates in roots of Canada thistle and sow thistle plants were least at flowering time. Hence we might expect that mowing at this stage of growth would be timely for starving the roots (10). Where a heavy stand of competitive crop (such as alfalfa) was present, mowing twice or more often in one season was effective in decreasing the Canada thistle infestation (32).

Meggit (44) found that cultural or smother crop methods of control would not completely eradicate this weed.

With the advent of the phenoxy herbicide 2,4-D, a selective chemical treatment for control of thistles as a supplement to cropping or cultivation methods or to replace them was made possible. Hodgson (33), Thrasher et al. (58), Schreiber (52), and Derscheid et al. (15) showed that combined cultural, cropping and chemical methods control Canada thistle. According to Halliday and Templeman (25) Canada thistle was susceptible to 2,4-D applied at the bud to early bloom stage, and Rasmussen (49) showed that 4 annual applications of 2,4-D at bud stage could control Canada thistle. Recent research has indicated that use of this chemical resulted in temporary topgrowth control but not eradication (19, 27). Heikes (27) stated that one application of 2,4-D amine, esters or emulsifiable formulations at the rates of 3 lb/A had little effect on Canada thistle. Friesen (18) applied 16 to 24 oz/A of 2,4-D ester to this species in 1964. By 1967, regrowth on the treated plots equalled that on the checks.

Two new chemicals, picloram (4-amino-3,5,6-trichloropicolinic acid) and dicamba (2-methoxy-3,6-dichlorobenzoic acid), have been evaluated for the control of Canada thistle and sow thistle. Results with dicamba for the control of thistles, have been quite variable. Adamson (1) achieved fair control with split applications of 4 lb/A. Friesen (18) applied 8 to 48 oz/A in 1964. By 1967, regrowth on the treated plots equalled that on the checks. Canada thistle treated at the early bloom stage with dicamba at 0.25, 0.5, 1 and 2 lb/A (31) showed respectively 6, 17, 17 and 1% regrowth 4 months after treatment, but was completely controlled after treatments with picloram at 0.25 lb/A or more.

The growth regulating properties of picloram were first described in 1963 (26). It has a range of activity similar to that of 2,4-D (26) i.e.

it generally is effective against broadleaf plants with grasses exhibiting moderate tolerance (4), but apparently translocates in a manner similar to that of dicamba in thistle plants (9) and has shown unusual herbicidal activity of low dosages (21). It has given outstanding control of various deep-rooted perennial weeds (3, 27, 38, 61). Of the three herbicides, picloram, dicamba, and 2,4-D, picloram is considered to be the most efficient in killing Canada thistle and sow thistle (3, 18, 19). Similar findings have been reported regarding whorled milkweed (Asclepias verticillata L.) (42). The superior effect of picloram is thought to be related to its mobility and greater toxicity into the root system of these plants (9, 37, 38, 39). Lanning (38), and Chang (9) concluded that picloram was readily translocated from the foliage to the roots of Canada thistle. Picloram treatment caused serious swelling of the creeping roots of Canada thistle but no such swelling was observed after the dicamba treatment (9). This was substantiated by Kreps and Alley (37) who reported swelling followed by complete deterioration of the roots of picloram-treated Canada thistle. Lee et al. (39) obtained similar results.

Warden (61) found good control of Canada thistle by picloram at dosages of 2 to 3 lb/A regardless of stage of plant growth at time of treatment. This apparent lack of significance of stage of growth at time of treatment may be due to the masked effect of perhaps excessively high doses of picloram, but this point is unsettled. Crafts (12, 13) has demonstrated that the movement of herbicide in the plant is accompanied and determined by the movement of assimilates. The success of foliage treatment was clearly more dependent on correct timing than on the dose used in the range of 1 to 3 kg/ha of MCPA and 2,4-D (60). Both MCPA and 2,4-D were most effective against sow thistle when the plants had developed large rosettes of leaves and the first flower buds were forming.

Picloram applied to Cirsium in early September was more effective than that applied in early June or July (59). At Scott, Saskatchewan fall applications of 4-12 oz/A of picloram controlled Canada thistle and perennial sow thistle regardless of the associated tillage treatment (36). Without injuring the grass with which Cirsium was growing, Hughes and Froese (34) using 8 oz/A picloram controlled the thistles. Alley (3) in Wyoming, obtained 100% control of Canada thistle with 1 lb/A of picloram applied to regrowth which had reached a height of approximately 2 inches after mowing of plants.

In general then, although results for the control of Canada thistle and sow thistle by the use of picloram have been quite encouraging, there are the factors of its residue in the soil (22, 23, 28) and its cost of about $24/lb that warrant consideration before making firm recommendations for its use. The use of relatively small amounts of picloram in mixtures with certain other herbicides might lessen such problems. Although literature concerning the herbicidal effects of picloram -2,4-D herbicide combinations is limited, there is little doubt that there have been situations when use of mixtures of these herbicides had advantages over use of 2,4-D alone (2, 43, 55).

Enhancement of herbicidal activity by added surfactant

The potential advantage of use of added surfactant to increase the toxic effect of small dosages of herbicide and thereby to reduce costs and to minimize chemical residue problems and hazards to wild life was also a pertinent consideration as part of the present work. Many different types of surfactants are employed by biological investigators (6, 56) not only to reduce surface tension but to maintain the herbicide longer in a fluid state as the aqueous carrier evaporates. There is also a direct effect of the surfactant on the plant's surface and/or the under-

lying tissue (35) and possible additional physiological effects. Addition of appropriate surfactant in adequate amounts to spray mixtures has improved the efficacy of herbicides in controlling specific weeds (35). The effect of the surfactant Atlox 210 in improvement of activity of picloram compounds on poplars has been clearly demonstrated by Corns and Dai (11). Related studies at the University of Alberta showed that the surfactant increased foliar penetration by picloram (53).

Application Methods

The application of herbicide can be made by many kinds of equipment including aircraft and ground operated boom and boomless sprayers including air blast types (13, 51). Drift is a hazard particularly with aerial spraying (50). Ground spray equipment is more suitable for application of a greater volume of spray containing the same amount of herbicide equivalent per unit area and heavier droplets (29). There can be problems with all methods of application particularly under unsuitable weather conditions. Often poor results occur because of poor application - uneven or poor coverage and improper selection of spray equipment. These are management aspects that can be corrected and are not the fault of the chemical.

Possible harmful or beneficial effects of herbicides on animal life and habitats

There is considerable evidence to indicate the safety for animal life of the phenoxy-type herbicides used at dosages recommended for weed control. Gysel (24) reported that power line right-of-ways sprayed with 2,4,5-T were very suitable for wild life. Ecological changes enhanced the value of habitat due to increased diversification of plant species and improved densities. In a similar study in Pennsylvania, Bramble *et al.* (8) reported that common game species used all sprayed areas the

first year following various treatments of a power line right-of-way with herbicides. This wild life use was maintained or increased over a five-year period. Based on one season's observations (41) a treatment with 2,4,5-T had no marked adverse effect upon nesting species of birds and actually improved the habitat for few species. On the other hand questionable results could come from broadcast spraying of large areas because certain plant species desirable as food or cover for wild life might be killed with the undesirables (7). Conceivably however such effects might be counterbalanced by the subsequent replacement of weedy species by more desirable types of vegetation. Differences among herbicides and the complexity of interactions between habitat and various forms of animal life make it advisable to consider each situation carefully before reaching decisions about the advantages or disadvantages of use of various herbicides to change habitats. Some aspects of this problem have also been discussed by Dwernychuk (16).

Lynn (40) showed that picloram was low in toxicity to a variety of test animals, including avian, mammalian and aquatic species. This held true whether the material was given orally, or applied to the skin or eyes. The relative toxicities of picloram, dicamba and 2,4-D to mammals, based on acute oral LD 50 in milligrams of chemical per kilogram of body weight for adult white rats are 8200, 1040, and 500 respectively. Fathead minnow, brown trout and rainbow trout fish were exposed for 96 hours to various concentrations of picloram and 100 ppm caused no observable effect (40). It requires a dosage of 2.7 lbs of active herbicidal ingredient per acre foot of water to provide a concentration of even one ppm. Chances of sufficient drift from lakeshore areas sprayed at dosages recommended for weed control to cause any harm to aquatic organisms appear therefore to be negligible.

MATERIALS AND METHODS

1. Greenhouse Experiments

(a) Prevention of flower and seed production of Canada thistle and perennial sow thistle

Experiments to determine the least amounts of various herbicides,* with and without added surfactant, required to prevent flowering of Canada thistle and perennial sow thistle, were conducted in the greenhouse, during the years 1966, 1967 and 1968. Sections of horizontal roots of Canada thistle and perennial sow thistle were selected during the spring of 1966 from growing plants at Miquelon Lake for propagation in 6-inch-diameter plastic pots under greenhouse conditions. Single plants per pot were established from single root sections about 3 inches long. In the greenhouse the temperature was maintained at approximately 20°C during the winter. During the summer, however, temperatures in excess of 35°C were occasionally experienced. Supplementary lighting was given during the winter months to provide illumination for 14 hours. According to the purpose of the experiment, plants were allowed to reach the appropriate stage of growth, then selected for approximately uniform size. Each treatment was replicated three times. The treatments applied for the various trials are shown in Table 1. Some of the dosages of 2,4-D at the upper end of the range tested were higher than the amounts whose toxicity might be expected to be limited to prevention of flower and seed production.

Foliage sprays were applied from an atomizer using an aqueous spray volume of 30 gal/A directed uniformly across the upper surface plane of an open topped walled enclosure containing the appropriate pots. Treated plants were returned to the greenhouse, where they were regularly observed for the development of visible symptoms in comparison with controls. The lack of bud formation or failure of opening of buds already present, was

* See appendix, page 60, for details of herbicidal formulations.

Table 1. Greenhouse experiments on prevention of flower and seed production of Canada thistle and perennial sow thistle.

Species	2,4-D oz/A a.e.*	Picloram oz/A a.e.		Dates Treated		
				Rosette	Early Bud	Late Bud
Canada thistle	24, 48	1, 2, 4, 8		May 13/66	May 30/66	June 30/66
Canada thistle & perennial sow thistle	8	.5		July 8/66	July 22/66	----------
Canada thistle & perennial sow thistle	4, 12, 24	.1, .5, 1.0				
	4, 8, 12 (+)**	.05, .25, .50	(+)	----------	May 1/66	----------
Canada thistle	1, 2, 4, 8	.05, .1, .5, 1.0				
		.05, .1, .5, 1.0	(+)	----------	Feb. 2/68	Feb. 2/68
	4, 6, 12, 24	.1, .25, 1.0, 2.0				
		.1, .25, 1.0, 2.0	(+)	----------	March 6/68	March 6/68

* Dosages of all herbicide applications are in terms of active ingredient or acid equivalent per acre. Kg/ha = oz/A x 0.070.

**Shows spray solutions contained 1% v/v of Atlox 210.

taken as evidence of the effect of herbicides for the prevention of flower formation.

(b) Control of vegetative growth of Canada thistle and perennial sow thistle

Reference has been made to greenhouse experiments for comparison of efficiency of herbicides for prevention of flowering of thistles without appreciable damage to their vegetative growth. An additional series of greenhouse experiments was conducted to evaluate various herbicidal treatments for general killing of the plants as an aid in planning of appropriate later field studies of this nature. Extent of top killing was assessed by continual visual observations and recorded as percentage of the control with regard to numbers and heights of shoots. The major greenhouse experiments are outlined in Table 2.

2. Field Experiments at Miquelon Lake and at Ellerslie

(a) Prevention of flower and seed production of Canada thistle and perennial sow thistle

At Miquelon Lake, the experimental site for plots treated for flower suppression was a saline lakeshore made up primarily of foxtail barley with a heavy infestation of Canada thistle and some sow thistle. In one of the experiments during 1967 treatments were applied from a knapsack sprayer with single fan type nozzle to 10' x 20' plots of predominantly Canada thistle, replicated three times in a randomised complete block design. Spray pressure did not exceed 40 p.s.i. At the time of spraying for these small plot experiments the plants were two and a half feet tall in early bud stage.

In an additional field study during 1967 a 13 h.p. Potts mist-blower hauled by a half ton truck at 3 m.p.h. delivered 1.6 gal/A aqueous preparation over a 30' swath laterally from a single nozzle outlet. Strips

Table 2. Greenhouse experiments on control of vegetative growth of Canada thistle and perennial sow thistle

Species	2,4-D oz/A a.e.*	Picloram oz/A a.e.	Dicamba oz/A a.e.	Dates Treated		
				Rosette	Early Bud	Late Bud
Canada thistle	24, 48	1, 2, 4, 8 (K) 8, 16 (Tordon 101-Appendix)	6, 12	May 13/66	May 30/66	June 20/66
Canada thistle & perennial sow thistle	4, 12, 24 4, 12, 24 (+)**	0.1, 0.5, 1.0 0.1, 0.5, 1.0 (+)		Dec. 18/66	Dec. 18/66	----------

* Dosages of all herbicide applications are in terms of active ingredient or acid equivalent per acre. Kg/ha = oz/A x 0.070.

** Shows spray solution contained 1% v/v of Atlox 210.

100 feet long of early to intermediate bud stage Canada thistle in dense infestation, were sprayed under almost calm conditions. Young potted bean plants placed down wind were used as indicators of spray drift. They were removed for transport to the greenhouse after spraying.

Similarly at Ellerslie near Edmonton, in the summer of 1967, additional experiments with small field plots and larger strips were conducted on fertile black clay loam soil in alfalfa pasture having a medium to heavy infestation of Canada thistle (smooth leaf form).

For small field plots, a 3' x 2' walled portable plywood enclosure was used to prevent drift during spray treatment of triplicate plots at early bud stage of the thistles on July 10, 1967.

The larger field scale experiment involved spraying on July 1, 1967. The equipment and gallonage employed were as described above for similar strips at Miquelon Lake. The various treatments applied at the two locations are shown in Table 3.

As noted earlier, under greenhouse experiments, some of the dosages of herbicides in the range tested were large enough to be expected to have effects on the plants exceeding the prevention of flowering and seed productivity.

The experimental sites were inspected periodically. Treatment effects were evaluated by recording the number of open flowers in triple yard square subplots twice during the season, once as soon as possible after the controls were in nearly full flower and later when control blossoms were ready to lose seeds.

(b) Field experiments on control of vegetative growth of Canada thistle at Ellerslie

A field experiment extending through 1966, 1967 and 1968 compared 2,4-D and picloram, including divided dosages of herbicides and mowing

Table 3. Field experiments at Miquelon Lake and at Ellerslie, on prevention of flower and seed production of Canada thistle and perennial sow thistle.

Species	2,4-D oz/A a.e.*	Picloram oz/A	Aqueous Spray gallons/A	Dates Treated	
				Early Bud	Late Bud
Miquelon Lake					
Canada thistle	1, 2, 4, 8, 32	0.5, .1, .25, 1.0, 2.0	20	July 22/67	--------
" "	4, 8, 32	0.1, 0.25, 1.0	1.6 (mist blower)	July 19/68	--------
" "	4, 8, 16, 32	0.1, 0.25, 0.5, 1.0	20	July 17/68	--------
	4, 8, 16, 32	0.25, 0.5, 1.0, 1.5	20	----------	July 31/68
Perennial Sow thistle	4, 8, 16, 32	0.1, 0.25, 0.5, 1.0	20	July 17/68	July 31/68
Ellerslie					
Canada thistle	1, 3, 6	0.025, 0.05, 0.1			
	1, 3, 6 (+)**	0.025, 0.05, 0.1	30	July 10/67	--------
" "	1, 4, 8	0.25, 0.5, 1.0	1.6 (mist blower)	July 1/67	--------

* Dosages of all herbicide applications are in terms of active ingredient or acid equivalent per acre. Kg/ha = oz/A x 0.070.

** Shows spray solution contained 1% v/v Atlox 210.

for control of Canada thistle on cropland at Ellerslie having a third year uniform stand of Canada thistle. The experiment was designed as a split-plot randomised block with four replicates. Main plots (mowing and spraying) and sub-plots (dosages of herbicides) treatments are summarized in Table 4.

Twelve and twenty-four months after the initial herbicide and mowing treatments, records were taken of numbers of shoots and of fresh weight of top growth of weeds per 9 square feet in the most heavily infested area within each plot.

(c) Field experiments on control of vegetative growth of Canada thistle and sow thistle at Miquelon Lake

At Miquelon Lake various herbicides were tested from 1966 to 1968 in one or more experiments for the control of thistles. In all experiments herbicides were applied with a small power sprayer equipped with a single fan type nozzle. All herbicides were applied as aqueous foliage sprays at 40 p.s.i. and 20 gal/A.

Unreplicated 1/40 acre plots on the saline shore margin at Miquelon Lake were sprayed on September 15, 1966 and 1967 (two independent experiments) with 1 oz/A picloram in water with or without added surfactant Atlox 210, 1% by volume. Treatments in one area nearest the lakeshore involved a heavy thistle infestation associated with foxtail barley. This area had been roto-tilled on July 5, 1966, and there was abundant thistle regrowth at spraying time. The other infested area, uncultivated, was farther from the water and had predominantly bluegrass (Poa species) and brome grass (Bromus species) as ground cover. Treatment effects were evaluated by comparing the number of Canada thistle plants in a yard square sample area per plot in the untreated area with the number remaining in the treated area a year after treatment.

Table 4. Field experiments on control of vegetative growth of Canada thistle at Ellerslie.

TREATMENT SCHEDULE	Herbicide dosages oz/A a.e. (Kg/ha = oz/A x 0.070			
	2,4-D		Picloram (+)*	
	Initially	Retreated	Initially	Retreated
A. Sprayed only at flowering stage	Aug. 12/66 16 32	Aug. 16/67 16 32	Aug. 12/66 4 2	Aug. 16/66 2 1
B. Sprayed ½ dose at flowering stage ½ dose in fall	Aug. 12/66 + Sept. 11/66 8 + 8 16 + 16	Aug. 16/67 + Sept. 13/67 8 + 8 16 + 16	Aug. 12/66 + Sept. 11/66 2 + 2 1 + 1	Aug. 16/66 + Sept. 13/66 1 + 1 0.5 + 0.5
C. Mowed at flowering stage (Aug. 12/66 and Aug. 16/67) and regrowth sprayed in September each year	Sept. 11/66 16 32	Sept. 13/67 16 32	Sept. 11/66 4 2	Sept. 13/67 2 1

* Shows spray solution contained 1% v/v Atlox 210.

An additional study at Miquelon Lake comprised a randomised complete block arranged in a split plot design. Application dates (August 17, September 15, 1966) constituted the main blocks. Plot treatments were randomised in triplicate within each block. Experimental plots 15' x 14.5', were laid out and a 3' border around each plot was regularly cultivated to check the invasion of weeds from outside. Treatments including the dates of spraying and three dosages of application for each of the four chemicals are given in Table 5.

Table 5. Field experiments on control of vegetative growth of Canada thistle and sow thistle treated with various herbicides on Aug. 17, 1966 and Sept. 15, 1966 at Miquelon Lake.

2,4-D	Dicamba	Picloram	Picloram + 2,4-D
oz/A a.e.*	oz/A a.e.	oz/A a.e.	oz/A a.e.
24, 48**, 96	6, 12, 24	4, 8, 16 (+)***	8, 16, 32 (+)

* Dosages of all herbicide applications are in terms of active ingredient or acid equivalent per acre. Kg/ha = oz/A x 0.070.
** Plots were retreated with 2 lb/A of 2,4-D in September, 1967.
*** Shows spray solution contained 1% v/v of Atlox 210.

The experimental sites were inspected periodically. Treatment effects were evaluated visually by two observers and recorded in terms of percentage control of thistles in comparison with the untreated checks. Plant species inventories also were assembled from year to year.

3. Aircraft applications as another aspect of field testing

Applications of 2,4-D from an aircraft flying about 12 feet above the ground were made in 1966 and 1967 on 65' x 750' strips at the west end of Miquelon Lake, an area moderately infested with thistles. The dosages of 2,4-D ethyl ester applied were 8 oz/A on one strip and 2 lb/A on another. Total volume was 1 gal/A in diesel fuel as the carrier. Mr. E.A. Havlick, field supervisor, Camrose M.D., arranged for the air

spraying by employing Evans Air Service, Stettler.

Young potted tomato plants in 1966 and bean plants in 1967 were placed at 10-foot intervals, 150 feet up and 400 feet downwind to act as indicators of spray drift from the spray operation. Wind velocity during the spray operation was approximately 15 m.p.h. in 1966 and 5 m.p.h. in 1967. The plants were removed to the greenhouse shortly after spraying for observation of progressive injury, if any, from spray drift.

RESULTS AND DISCUSSION

1. Greenhouse Experiments

(a) Prevention of flower and seed production of thistles

CANADA THISTLE

In the preliminary experiments where 2,4-D ethyl ester (24, 48 oz/A) and picloram (1, 2, 4, 8 oz/A) were applied to Canada thistle plants in their respective rosette, early bud and late bud stages of growth on May 13, 20 and June 30, 1966, these herbicidal dosages applied at rosette and early bud stage were more than sufficient for complete control of Canada thistle flowering and seed production. There was extensive killing of vegetative growth as well. Of the treatments at late bud stage (approximately one week before the beginning of flowering when the coloration of the top of the corolla is just beginning to be visible), only high dosages, 48 oz/A of 2,4-D and 2, 4 and 8 oz/A of picloram completely prevented flowering.

After this preliminary study the same herbicides were tested at lower dosages down to 4 oz/A of 2,4-D and 0.1 oz/A of picloram in two experiments with Canada thistle at rosette and early bud stage. All of the treatments included in these two experiments resulted in 100% control of flowering of Canada thistle treated at rosette and early bud stage (fig. 1). Therefore the further testing of these herbicides at even lower dosages down to 1 oz/A of 2,4-D and 0.05 oz/A of picloram was carried out (Table 1).

The results of such greenhouse trials clearly indicated that 4 oz/A of 2,4-D ethyl ester and 0.1 oz/A of picloram are near the lower limits for use for complete prevention of flowering of Canada thistle treated at early bud stage (Table 6).

Figure 1. Comparative effects of 2,4-D and picloram on flower prevention of Canada thistle treated at early bud stage. From left to right - Control, picloram 0.1 oz/A, 2,4-D 4 oz/A and regrowth from untreated plant which had been cut off at ground level at the beginning of the test (6 weeks after treatment).

Table 6. Summary of representative data showing control of flowering in Canada thistle by 2,4-D and picloram treatments at two growth stages of Canada thistle in the greenhouse (means of three replicates).

2,4-D oz/A a.e.	Early bud stage	Late bud stage	Picloram oz/A	Early bud stage	Late bud stage
1	60	19	.05	71	28
2	75	60	.1	100	44
4	100	75	.25	100	50
6	100	82	.50	100	63
8	100	88	1.00	100	74
12	100	92	2.00	100	100
24	100	100	4.00	100	100

Data represent flower counts as 100 - (number after treatment/number control) x 100.

PERENNIAL SOW THISTLE

Complete flower prevention for perennial sow thistle in the greenhouse was achieved with 8 oz/A of 2,4-D and 0.5 oz/A of picloram when applications were made prior to bud stage, but sprayed at bud stage these dosages were inadequate for 100% control of flowering of this weed. Results obtained with two additional trials involving spraying at rosette and early bud stages were different from the earlier findings in the greenhouse. In these later trials with perennial sow thistle the results were comparable to those obtained with Canada thistle in that 0.1 oz/A of picloram and 4 oz/A of 2,4-D ester when applied at rosette or early bud stage resulted in complete control of flowering. Differences in response of the two species under field conditions indicating greater resistance of perennial sow thistle than Canada thistle to low dosages of herbicides for flowering prevention will be discussed later.

The results from the greenhouse pot experiments presented so far indicate that the stage of growth during the season is a factor of major importance concerning the effect of applied growth regulators for the control of flowering of Canada thistle and perennial sow thistle. Both

picloram and 2,4-D were most effective against Canada thistle prior to the weed's late bud stage and against perennial sow thistle at prebud stage These data are of interest for comparison with results from field trials at Lacombe (19) which indicate that application of picloram at the rate of 1.5 oz/A or higher when thistles had 4-5 leaves inhibited vegetative growth and prevented flowering throughout the season. The present tests indicate the possibility of effective use of rates of picloram lower than 1.5 oz/A for prevention of flowering.

(b) Control of vegetative growth of Canada thistle and perennial sow thistle

CANADA THISTLE

Results from an experiment in 1966 on the effect of 2,4-D ethyl ester, picloram, dicamba, and picloram + 2,4-D (Appendix 1) on the vegetative growth of Canada thistle in the greenhouse appear in Table 7. The response to treatments at late bud stage was far less than it was at either early bud stage or at the young plant stage. The reduced response when treatments were made at late bud stage might have been due to the absence of actively developing tissue which is usually more sensitive to herbicidal toxicity. Although the injury symptoms on old shoots were not very pronounced, injury to the young sprouts of regrowth from roots of plant treated with either picloram or dicamba was evident. Plants treated with 2,4-D produced sprouts of normal appearance thus indicating limited translocation of this herbicide.

On the basis of these studies, the herbicides were rated in order of decreasing effectiveness to be picloram alone or in combination with 2,4-D > dicamba > 2,4-D. Weakest regrowth occurred after treatments with picloram or a picloram containing product. Regrowth occurred only after treatments at early bud or late bud stage. When treated at rosette stage potted plants were probably killed before they had a chance to

Table 7. Comparisons of toxicity of herbicides applied at different growth stages of Canada thistle in the greenhouse (means of three replications - Visual assessment of extent of top-killing 3 weeks after the treatment).

HERBICIDE	Rate oz/A a.e.	Treatment dates and % control		
		Rosette	Early Bud	Late Bud
		May 13/66	May 30/66	June 30/66
2,4-D ethyl ester	24	96	56	40
	48	100	77	60
Dicamba	6	90	80	80
	12	100	100	80
Picloram	1	90	87	77
	2	96	87	77
	4	100	97	80
	8	100	97	83
Picloram + 2,4-D	8	100	93	50
	16	100	97	67

develop a good root system. Evaluations of growth in pots after treatment at early bud stage in a supplementary experiment showed regrowth of Canada thistle to be 76, 66 and 30% after picloram at 0.1, 0.5 and 1.0 oz/A as compared with the amount of new growth in control plots (fig. 2 in part). The extent of new growth was 100, 45 and 53% after 2,4-D treatment at 4, 12 and 24 oz/A, respectively. As noted earlier this growth was not deformed and chlorotic as it was in picloram and dicamba treated material. Again the much greater effectiveness of picloram than 2,4-D at low dosage was evident.

PERENNIAL SOW THISTLE

In the greenhouse the sow thistle appeared to be more susceptible than Canada thistle to injury from treatments with picloram or 2,4-D (Table 8). Irrespective of the chemical and dosage applied (Table 8) sow thistle like Canada thistle, showed less top killing after treatments

Figure 2. Comparative effects on vegetative growth of Canada thistle, of picloram with and without surfactant. From left to right - control, picloram 0.5 oz/A, picloram 1 oz/A, picloram 1 oz/A plus surfactant.

at the bud stage than after comparable treatments at the rosette stage of growth. Unlike Canada thistle, no regrowth was noticed from treated or untreated plants of perennial sow thistle in the greenhouse pots.

(c). Effect of added surfactant, Atlox 210

Combination of picloram with surfactant generally resulted in appearance of leaf burning effects within two days after treatment. Without surfactant, treatments usually caused symptoms of injury within 4-6 days or later depending upon the concentrations of picloram used. The results recorded 6 weeks after treatment showed some remarkable differences in extent of injury among various concentrations of picloram with and without Atlox 210 (Table 8).

Table 8. Comparison of the effect on Canada thistle and sow thistle of 2,4-D and picloram with and without surfactant Atlox 210 in the greenhouse. (Means of three replications - treated on December 18, 1966, evaluations made 6 weeks after treatment).

HERBICIDE	Rate oz/A a.e.	Stage of treatment and % control (top kill)			
		Canada thistle		Perennial sow thistle	
		Rosette	Early bud	Rosette	Early bud
2,4-D	4	57	53	100	80
	12	97	77	100	93
	24	100	100	100	97
2,4-D + 1% Atlox 210	4	60	58	100	80
	12	100	79	100	100
	24	100	100	100	100
Picloram	0.1	57	47	60	47
	0.5	83	57	100	80
	1.0	100	93	100	97
Picloram + 1% Atlox 210	0.1	77	70	100	80
	0.5	100	100	100	100
	1.0	100	100	100	100

Surfactant enhanced the top killing activity of picloram herbicides applied at the lower dosages but it had little effect on the results with 2,4-D ethyl ester (Table 8). As regards flower and seed production,

the beneficial effect of added surfactant was not apparent except under the more resistant conditions of the thistles treated at the late bud stage. In the greenhouse, addition of Atlox 210 to picloram potassium salt, improved its effectiveness in killing both tops and roots of Canada thistle. Evaluations of pots after the treatment showed no regrowth of Canada thistle after 1 oz/A picloram + Atlox 210 1%. Regrowth was 30% after picloram treatments at the same dosage without surfactant (fig. 2). Similar results were noted with perennial sow thistle for killing tops only. Since there was no regrowth in any sow thistle pot with or without treatment, this aspect could not be evaluated in perennial sow thistle.

Since addition of Atlox 210 to either of the chemicals did not result in reduction of its dosages for use for complete seed set prevention in Canada thistle and perennial sow thistle in the greenhouse very little emphasis was placed on its use for this purpose in the ensuing field experiments. Since there appeared to be a distinct advantage of adding the surfactant to picloram to aid in reduction of regrowth from treated plants, Atlox 210 was however, included in all herbicidal applications of picloram formulations for vegetative growth control in the field studies described in the next section.

2. Field Experiments at Miquelon Lake and at Ellerslie

(a) Prevention of flower and seed production of thistles

CANADA THISTLE

Poor results for prevention of flowering of Canada thistle were achieved at Miquelon Lake from 1 and 2 oz/A dosages of 2,4-D (Table 9) applied from a knapsack sprayer to 10 x 20 feet plots.

Only the higher rates of 8 oz/A and 32 oz/A of 2,4-D gave 100% control. Where picloram was used from 0.05 to 2 oz/A there was 87 to

Table 9. Percentage control of flowering of Canada thistle at Miquelon Lake by 2,4-D and picloram applied from a knapsack sprayer to 10 x 20 feet plots on July 25, 1967 (means of three replicates).

2,4-D oz/A	% Control 1967		Picloram oz/A	% Control 1967	
	Aug. 24	Sept. 13		Aug. 24	Sept. 13
1	13 d	27 d	.05	87 b	88 b
2	44 c	57 c	.10	91 b	92 b
4	79 b	83 b	.25	100 a	100 a
8	100 a	100 a	1.00	100 a	100 a
32	100 a	100 a	2.00	100 a	100 a
CONTROL	277	410 (number of open flowers/yd^2).			

Means followed by unlike letters in the same column are significantly different at the 5% level (57).

100% prevention of flower production of Canada thistle. Application of 0.25 oz/A picloram or higher increased percentage control significantly over that from 0.05 and 0.1 oz/A. There were no significant differences among the higher rates of picloram since 0.25, 1 and 2 oz/A, all were completely effective.

Similar results were obtained in 1968 trials when applications were made at early bud stage of the thistles. In one experiment four ounces of 2,4-D was not sufficient to prevent flowering of Canada thistle treated in early bud stage. Picloram was completely effective when used at the low rate of 0.25 oz/A. Eight ounces of 2,4-D was required to be as effective as 0.25 oz/A of picloram. This conclusion is supported by the data for the small plot experiments and for field scale application by mist blower experiments (Tables 9 & 10).

Table 10. Percentage control of flowering of Canada thistle at Miquelon Lake, treated at early bud stage on July 19, 1967 with 2,4-D and picloram applied by mist blower (means of three observations on 9 sq. ft. areas per strip).

2,4-D oz/A	% Control 1967		Picloram oz/A	% Control 1967	
	Aug. 24	Sept. 13		Aug. 24	Sept. 13
4	84	82	0.10	100	100
8	100	100	0.25	100	100
32	100	100	1.00	100	100
CONTROL	405	534 (number of open flowers/yd^2).			

In another study at this site in 1968 when the population of Canada thistle present at the time of treatment was composed of early bud and late bud stages of growth, percentage control of flowering of marked plants in late bud stage was 57, 84, 93 and 100% after 2,4-D treatments at 4, 8, 16 and 32 oz/A respectively. Picloram at 0.25, 0.5, 1.0 and 1.5 oz/A resulted in 52, 71, 95 and 100% control.

The extent of top killing of top growth of Canada thistle by higher dosages of both herbicides viz. 32 oz/A for 2,4-D and 1.5 oz/A for picloram was about 70 to 80%, sufficiently great to discourage the use of such high dosages to prevent seed production of the thistles without killing their vegetative cover.

From these results it may be concluded, as it was also found in the greenhouse study, that picloram was the more effective of the two chemicals. Buds surviving picloram applications at 0.25 oz/A or higher prior to late bud stage did not reach flowering stage. All buds were black and deformed. If the spraying is left until the late bud stage, it would not be possible to recommend the use of picloram or 2,4-D to prevent seed set in Canada thistle without damaging its vegetative

growth under conditions such as those found at Miquelon Lake.

Supplemental experiments covering a somewhat different range of treatments and soil conditions were conducted at Ellerslie near Edmonton (Tables 11 & 12).

Table 11. Percentage control at Ellerslie of flowering of Canada thistle treated at early bud stage on July 10, 1967 with 2,4-D and picloram with and without added surfactant Atlox 210 (means of three replicates).

2,4-D oz/A	% Control 1967 Aug. 2	Sept. 5	Picloram oz/A	% Control 1967 Aug. 2	Sept. 5
1	35 c	33 c	0.025	52 c	53 c
3	83 b	70 b	0.050	81 b	78 b
6	93 a	95 a	0.100	92 a	92 a
1 +*	28 c	26 c	0.025 (+)*	52 c	51 c
3 +	93 a	91 a	0.050 (+)	90 a	86 a
6 +	96 a	96 a	0.100 (+)	93 a	91 a
CONTROL	138	208 (number of open flowers per yd^2).			

Means followed by unlike letters in the same column are significantly different at the 5% level (57).
* Shows spray solutions contained 1% v/v of Atlox 210.

Table 12. Percentage control at Ellerslie of flowering of Canada thistle treated at early bud stage on July 1, 1967 with 2,4-D and picloram applied by mist blower (means of three observations on 9 sq. ft. area per strip).

2,4-D oz/A	Percent Control Aug. 2	Sept. 5	Picloram oz/A	Percent Control Aug. 2	Sept. 5
1	77	71	0.1	100	100
4	92	88	0.5	100	100
8	100	100	1.00	100	100
CONTROL	151	214 (number of open flowers/yd^2).			

Trends of results were similar (Table 12) to those obtained at Miquelon Lake but at Ellerslie (Table 11) none of the treatments involving dosages up to 6 oz/A of 2,4-D and up to 0.1 oz/A of picloram brought about 100% control of flowering in Canada thistle. This indicates that 0.1 oz/A of picloram and 6 oz/A of 2,4-D are submarginal for complete elimination of flowering in Canada thistle under field conditions.

It seems likely that greater effect from lower dosages in the greenhouse experiments as compared with field experiments may be mainly due to differences in growth conditions. Plants developing under warm and humid greenhouse conditions will usually have more delicate tissues than those under field conditions. Hence they may be expected to be more susceptible to herbicides than are well established field grown plants whose roots are not confined to small pots. Another factor might be superiority of spray coverage and retention under the greenhouse conditions. On the basis of these experiments it appears that 8 oz/A of 2,4-D or 0.25 oz/A of picloram are probably practical dosages for prevention of flowering of Canada thistle if applied early enough in the growth cycle of Canada thistle i.e. at the early bud stage. The results offer the possibility of using relatively low rates of picloram to prevent flower formation and seed set of Canada thistle and yet retain the vegetative top growth if desired as a natural cover for wild life. Under other conditions these low rates of picloram might also be used selectively to eliminate the flowering of Canada thistle while allowing cropping of agricultural lands to continue. Not only would low rates make treatment more economical but also lessen or avoid any problems involving herbicide residue in the soil.

PERENNIAL SOW THISTLE

The population of perennial sow thistle present at time of treatment on July 17, 1968 was composed of rosettes, late prebud, early bud and late bud stages of growth. Results from treatments were very different from those obtained in the greenhouse. Although 0.1 oz/A picloram was effective in the greenhouse one ounce of picloram per acre was not sufficient to prevent flowering of perennial sow thistle when treated at early or late bud stage at Miquelon Lake. 2,4-D was completely effective at the high rate of 2 lb/A applied at late bud stage and 1 lb/A or higher at early bud stage. However, 2,4-D at 1 lb/A or higher resulted in practically complete top killing of the sow thistle by the end of August 1968. Since there was virtually complete killing of perennial sow thistle top growth with 1 and 2 lb/A of 2,4-D there appears to be no support for recommending use of such high dosages of 2,4-D simply to prevent seed set in budding perennial sow thistle under conditions found at Miquelon Lake. However plants which were not yet in bud stage at the time of treatment did not reach flowering stage after 2,4-D at 8 oz/A or 0.25 oz/A of picloram. These dosages caused some deformation of top growth but did not kill it. It may be concluded from our field observations therefore that 8 oz/A of 2,4-D or 0.25 oz/A of picloram should be practical dosages for mixed stands of Canada thistle and perennial sow thistle if treated prior to late bud stage of Canada thistle and just prior to early bud stage of perennial sow thistle when it is desired to prevent flower formation without appreciable damage to top growth.

(b) Control of vegetative growth of thistles

CANADA THISTLE

The results of the experiment dealing with eradication of Canada thistle at Ellerslie show the advantage of mowing the plants at

Table 13. Effects on Canada thistle survival at Ellerslie of various repeated herbicide treatments alone or in combination with mowing. (Number of Canada thistle shoots and their fresh weight gms. per 9 sq. ft. on August 10, 1967, one year after initial treatments - means of 4 replicates).

Treatments	Oz/A (1966)	A*	B	C
		Number of Shoots		
Check	0	68 a	66 a	66 a
Picloram (K salt)	2	46 b	51 b	33 cd
	4	35 c	40 c	29 d
2,4-D Ethyl ester	16	62 a	59 ab	43 b
	32	51 b	61 a	40 bc
		Fresh Weight in Gms.		
Check	0	2430 a	2333 a	2142 a
Picloram (K salt)	2	870 c	1123 c	700 c
	4	509 d	839 d	415 d
2,4-D Ethyl ester	16	1384 b	1517 b	1016 b
	32	1272 b	1390 b	932 b

*A - Sprayed at flowering stage, August 12, 1966 (unmowed).
B - Sprayed 1/2 dose at flowering stage, 1/2 September 11, 1966.
C - Mowed at flowering stage, sprayed regrowth (7") September 11, 1966.
Means followed by unlike letters in the same column are significantly different at the 5% level (57).

flowering stage followed by herbicidal treatments of the regrowth during the same year (Table 13) and in the following year (Table 14). With regard to effects on number of thistle shoots during the first year after treatments there were no clear overall differences between results from spraying with 16 or 32 oz/A 2,4-D or 2 or 4 oz/A picloram only at flowering stage (A), spraying 1/2 dose at flowering stage, 1/2 dose in the fall (B) and mowing at flowering stage followed by spraying of regrowth in the fall (C). With regard to reduction in fresh weight of treated material, however, the data showed significant superiority of treatments involving spraying in the fall after earlier mowing. Alley (3) reached the same conclusion from similar work involving one pound

Table 14. Effects on Canada thistle survival at Ellerslie, of various repeated herbicide treatments alone or in combination with mowing. (Number of Canada thistle shoots and their fresh weight gms. per 9 sq. ft. on August 9, 1968 - two years after initial treatments and one year after second treatments - means of 4 replicates).

Treatments	Oz/A 1966	Oz/A 1967	A*	B	C
			Number of Shoots		
Check	0	0	76 a	86 a	77 a
Picloram (K salt)	2	1	27 c	32 c	11 c
	4	2	8 d	9 d	3 c
2,4-D Ethyl ester	16	16	66 a	55 b	31 b
	32	32	49 b	39 c	26 b
			Fresh Weight in Gms.		
Check	0	0	1534 a	1584 a	1285 a
Picloram (K salt)	2	1	420 c	438 b	133 bc
	4	2	129 d	146 c	41 c
2,4-D Ethyl ester	16	16	739 b	639 b	325 b
	32	32	679 b	540 b	156 bc

*A - Sprayed at flowering stage, August 12, 1966 and August 16, 1967 (unmowed).
B - (i) Sprayed 1/2 dose at flowering stage - August 12, 1966 and August 16, 1967 (unmowed).
(ii) Sprayed 1/2 dose in the fall, September 11, 1966, and September 13, 1967 (unmowed).
C - (i) Mowed at flowering stage - August 12, 1966 and August 16, 1967.
(ii) Sprayed regrowth (7") - September 11, 1966 and September 13, 1967.

Means followed by unlike letters in the same column are significantly different at the 5% level (57).

picloram per acre. A similar general trend in results was noticed during the second year (1968). These different procedures (A, B and C) were found in order of decreasing effectiveness to be: mowed at flowering stage and sprayed regrowth > sprayed only at flowering stage > sprayed 1/2 dose at flowering stage, 1/2 dose in fall, with regard to reduction of regrowth of shoots and of their fresh weights after treatments with 2 and 4 oz/A of picloram. The same generalization applies

to the results with 2,4-D except that with 2,4-D at 16 and 32 oz/A the results of application of a single dosage at flowering stage of the thistles were inferior to the results from applications of two equal dosages totalling the same amount, one half applied at flowering stage, the other half a month later. Nevertheless, results with picloram were best regardless of the technique used. The numbers of shoots as well as their fresh weights were reduced spectacularly in treatments involving 4 oz/A of picloram. Where regrowth occurred, such survivors showed severe plant deformities typical of picloram. In every instance the effects of 2 oz/A of this herbicide were greater than those from 2 lb/A of 2,4-D.

About 85% control was obtained from treatments involving mowing thistle at flowering stage plus spraying of 7-inches-tall regrowth with picloram at a dosage of 2 oz/A during 1966 followed by retreatment of the thistles mainly by annual weeds is illustrated by Figure 3. Stunted thistle survivors remained beneath the replacement cover shown in the photograph. Over 96% thistle control was obtained from the larger dosages of picloram (4 oz/A 1966, 2 oz/A 1967) (Table 14).

Simpler trials with low dosages of picloram were performed on saline lakeshore vegetation at Miquelon Lake. In this case a severe infestation of Canada thistle was controlled effectively with 1 oz/A of picloram (Table 15, Figures 4 & 5). Chemical treatment was applied in September of 1966 to Canada thistle on an area which had been rototilled on July 5, 1966. There was abundant thistle regrowth about 6 inches tall at spraying time. Results by September 1968 from the same chemical treatment in 1966 on an uncultivated area which was retreated with 0.5 oz/A picloram in the fall of 1967, were very similar to those for the rototilled area. It is evident from the table (15) that as little as one

Figure 3. Appearance after a dense stand of Canada thistle at Ellerslie was mowed August 12, 1966 and August 16, 1967 and regrowth sprayed on September 11, 1966 and September 13, 1967 with picloram 2 oz/A and 1 oz/A respectively. Photographed on August 10, 1968. Above - control. Below - treated.

Figure 4. A dense stand of Canada thistle at Miquelon Lake was treated September 15, 1966 with picloram at 1 oz/A + surfactant and photographed one year later. Foreground shows succeeding cover mainly of brome grass and bluegrasses in treated area. Background - control area, still almost a pure stand of Canada thistle.

Figure 5. Mixed Canada thistle and perennial sow thistle infested area was rototilled during July 1966 and regrowth sprayed on September 15, 1966 with picloram at 1 oz/A. Photographed August 1967. Foreground about 95% cover of foxtail barley which also maintained dominance throughout 1968. Background-control.

Table 15. Number of Canada thistle shoots per 9 sq. ft. in 1/40 acre plots at Miquelon Lake (means of three observations) treated with various herbicides on September 15, 1966 and 1967.

Treatment	oz/A	A (pretilled)		B* (uncultivated)	
		1967	1968	1967	1968
Picloram	1	5	1	37	1
Picloram (+ 1% Atlox 210)	1	3	1	20	1
Check		165	79	137	67

* Retreated with 0.5 ounce per acre picloram in fall 1967.

ounce of picloram per acre applied to a dense stand of Canada thistle resulted in 90% reduction of thistle regrowth in association with competing foxtail barley. The herbicidal treatments in a sense, hastened the plant succession to achieve a vigorous uniform cover of foxtail barley about 23 inches tall (fig. 5).

One might conclude from these tests that saline lakeshore environmental and soil conditions make possible the effective use of dosages of picloram herbicide of the order of 2 oz/A for easy removal of the weedy non-native Canada thistle. On the other hand as indicated earlier, control may be confined to seed prevention, by use of as little as 0.25 oz/A picloram.

PERENNIAL SOW THISTLE

Results from treatment of the 1/40 acre plots of perennial sow thistle (Table 16) at Miquelon Lake with one ounce per acre, of picloram were very similar to those obtained after spraying regrowth of Canada thistle as discussed in the foregoing section. One ounce of picloram/A resulted in 94% control of perennial sow thistle a year after treatment

Figure 6. A perennial sow thistle infested area was rototilled during July 1967 and the regrowth sprayed on September 15, 1967 with picloram at 1 oz/A plus surfactant. Photographed August 1968. Foreground - foxtail barley almost free of thistles. Background - control.

Table 16. Number of perennial sow thistle shoots per 9 sq. ft. in 1/40 acre plots at Miquelon Lake (means of three observations) treated with various herbicides on September 15, 1967.

Treatment	oz/A	August 1968
Control	-	129
Picloram	1	24
Picloram + 1% Atlox 210	1	8

(Table 16). The native grass vegetation was not damaged by the one ounce per acre dosage of picloram. Grass cover in treated area a year after treatment was dense with only a few scattered plants of thistles (fig. 6).

Control of thistles and changes in associated vegetation

Additional more comprehensive herbicidal trials on replicated plots at Miquelon Lake (fig. 7) have indicated outstanding superiority of picloram at 4 oz/A per acre in suppression of Canada thistle and perennial sow thistle. Of the four chemicals tested, 2,4-D, dicamba, picloram (K salt) and picloram + 2,4-D (Tordon 101), the most consistent and effective control was given by picloram formulations. All dosages tested in these experiments involving two stages of treatments on August 17, 1966 or on September 15, 1966 produced excellent control of thistles (Table 17 & 18). Picloram was the only herbicide completely effective against the thistles. Initial control was excellent and effects from 0.25, 0.50, and 1 lb/A picloram treatments applied in 1966 lasted at least 2 years (Table 17 & 18). Equally effective results appeared to have been obtained from the use of picloram + 2,4-D (Tordon 101). In no instance was 4 oz/A of picloram or 8 oz/A of picloram + 2,4-D, inferior to applications of four times that amount of picloram or picloram + 2,4-D respectively. There

Figure 7. General condition of experimental area prior to herbicidal treatments summarized in Tables 17, 18, 19.

Table 17. Number of Canada thistle and sow thistle shoots per 9 sq. ft. in 15 x 14.5' plots at Miquelon Lake treated with various herbicides on August 17, 1966. (means of three replicates).

Herbicide	oz/A	Observation Times: Before treatment	After treatment		% Control	
		Aug./66	Aug./67	Aug./68	Aug./67	Aug./68
Check	-	50	60	56	0	0
2,4-D	24	38	32	41	16	0
2,4-D	48**	45	25	23	44	49
2,4-D	96	38	28	25	26	34
Dicamba	6	58	16	30	72	49
Dicamba	12	41	8	19	81	54
Dicamba	24	43	3	6	93	86
Picloram	4	38	0	0	100	100
Picloram	8	41	0	0	100	100
Picloram	16	41	0	0	100	100
Picloram + 2,4-D	8	39	0	0	100	100
Picloram + 2,4-D	16	46	0	0	100	100
Picloram + 2,4-D	32	41	0	0	100	100

* Data represent shoot counts as 100- (number after treatment/number before treatment) x 100.

** Plots were retreated with 2 lb/A 2,4-D in September 1967.

Table 18. Number of Canada thistle and sow thistle shoots per 9 sq. ft. in 15 x 14.5' plots at Miquelon Lake treated with various herbicides on September 15, 1966 (means of three replicates).

Herbicide	oz/A	Observation Times: Before treatment	After treatment		% Control*	
		Aug./66	Aug./67	Aug./68	Aug./67	Aug./68
Check	--	52	56	49	0	0
2,4-D	24	40	31	33	22	17
2,4-D	48**	44	24	24	44	44
2,4-D	96	44	33	25	25	43
Dicamba	6	37	12	21	68	46
Dicamba	12	37	7	17	81	54
Dicamba	24	34	2	5	94	85
Picloram	4	44	0	0	100	100
Picloram	8	38	0	0	100	100
Picloram	16	44	0	0	100	100
Picloram + 2,4-D	8	38	0	0	100	97
Picloram + 2,4-D	16	46	0	0	100	100
Picloram + 2,4-D	32	46	0	0	100	100

* Data represent shoot counts as 100- (number after treatment/number before treatment) x 100.

** Plots were retreated with 2 lb/A 2,4-D in September, 1967.

was no reinfestation in plots treated with picloram and its formulations during the duration of our studies covering a period of two years after treatments. Figure 8 illustrates the thistle-free condition of a supplementary plot area 2 years after treatment with picloram at 6 oz/A.

The Canada thistle and perennial sow thistle in some of the plots at Miquelon Lake had been sprayed singly or twice (Tables 17 & 18) with 2,4-D with little effect in the final population (Tables 17 & 18). Shoot counts in 1968 on the 2,4-D, 1.5 lb/A treated plots were equal to those for unsprayed plots. Somewhat better control but still less than 50% was obtained with the double applications, the first at 3 and the second at 2 lb/A of 2,4-D than with the single application of 6 lb/A.

Although dicamba appeared to be more toxic to thistles than did 2,4-D there was incomplete prevention of Canada thistle and perennial sow thistle regrowth by all the dosages of six to twenty-four ounces dicamba per acre (Tables 17 & 18). These results indicate that dicamba is intermediate between 2,4-D and picloram in injury to Canada thistle and perennial sow thistle.

The foregoing superior results concerning picloram substantiate conclusions reached by Heikes (27) who found that with several deep-rooted perennials, including Canada thistle, picloram was more effective than the phenoxy herbicides and dicamba. He also found that stage of growth at time of treatment did not seem to be a critical factor.

In our experiments also the results in 1967 and 1968 of both sets of treatments (Tables 17 & 18) were closely comparable indicating that time of treatment from early bloom to late bloom (fall) was without appreciable effect on the degree of control of either Canada thistle or perennial sow thistle. Similar results were reported by Warden (59) after working with Canada thistle and field bindweed.

Figure 8. A mixed stand of Canada thistle and perennial sow thistle at Miquelon Lake was treated September 15, 1966 with 6 oz/A of picloram and photographed 2 years later. At this time (August 30, 1968) there had been no regrowth of thistles.
Foreground - foxtail barley cover in treated area.
Background - thistle infested control.

It remains to discuss further the consequences of suppression of the vegetative growth of thistles in relation to associated plant species. Because results in 1967 and 1968 of both sets of vegetation suppression treatments with the various herbicides (Tables 17, 18) were nearly identical, the cover data for only one group are given viz. sprayed at flowering stage (August 17, 1968) (Table 19). In general the broad-leaved dicotyledonous plants included in the observations relative to changes in cover induced by the herbicide treatments decreased in their percentage cover. This effect was of course clearest with regard to Canada thistle and sow thistle since they comprised a major and relatively uniform component of the cover initially. Other dicotyledonous species were scattered and less frequent in occurrence. Cinquefoil (Potentilla anserina) for example did not occur in the control plots. Because of the limited number and low growing habit of the non-weedy species present their significance with regard to cover value for wildlife is open to question.

As noted earlier the grasses increased substantially as a result of the most effective herbicide treatments. Baltic rush either remained about the same or gained in percentage cover. The increase was most evident following picloram treatments. Foxtail barley, in areas most heavily treated with picloram and dicamba did show some stunting and onion leafing during the year after the treatments but the effect had disappeared by 1968.

It appears that in a relatively short term program intended for eradication of thistles under conditions such as those existing at Miquelon Lake there is no advantage in using more than 4 oz/A picloram initially followed by smaller dosages later if retreatments are necessary. It appears that even smaller dosages would be quite useful

Table 19. Percentage ground cover before treatment (Aug. 1966) a year after treatment (1967) and two years after treatment (1968) at Miquelon Lake (visual estimates - means of three replications).

HERBICIDE	oz/A	Year	Bare ground	Perennial[1] sow thistle	Canada[2] thistle	Foxtail[3] barley	Dandelion[4]	Saline[5] goose foot	Cinque-foil[6]	Baltic[7] rush	Red[8] clover
Control	-	1966	0	60	18	7	10	3	0	2	0
	-	1967	0	58	12	12	11	4	0	3	0
	-	1968	0	55	10	14	13	6	0	2	0
2,4-D	24	1966	0	63	9	15	8	3	0	2	0
		1967	0	52	6	35	5	0	0	2	0
		1968	0	55	8	23	6	5	0	3	0
	48 +	1966	0	63	13	11	10	3	0	0	0
	32	1967	0	37	8	47	6	2	0	0	0
		1968	0	31	6	48	7	8	0	0	0
	96	1966	0	65	4	9	10	5	4	3	0
		1967	0	46	3	39	7	2	0	3	0
		1968	0	41	2	47	7	0	0	3	0
Dicamba	6	1966	0	68	10	7	8	3	2	2	0
		1967	0	20	3	69	3	0	3	2	0
		1968	0	35	5	46	11	2	0	1	0
	12	1966	0	70	4	10	10	3	3	0	0
		1967	5	14	1	76	0	0	4	0	0
		1968	0	30	2	45	17	6	0	0	0
	24	1966	0	60	13	12	12	0	0	3	0
		1967	5	5	2	83	0	0	0	5	0
		1968	3	6	3	70	7	1	5	5	0
Picloram	4	1966	0	65	8	8	12	2	2	3	0
		1967	2	0	0	92	0	0	0	6	0
		1968	0	0	0	87	2	0	0	11	0
	8	1966	0	55	18	7	13	1	3	3	0
		1967	10	0	0	85	0	0	0	5	0
		1968	4	0	0	83	0	0	0	13	0

Table 19. Continued.

HERBICIDE	oz/A	Year	Bare ground	Perennial[1] sow thistle	Canada[2] thistle	Foxtail[3] barley	Dandelion[4]	Saline[5] goose foot	Cinque-[6] foil	Baltic[7] rush	Red[8] clover
Picloram	16	1966	0	70	8	8	7	2	0	5	0
		1967	17	0	0	67	0	0	0	16	0
		1968	6	0	0	71	0	0	0	23	0
Picloram + 2,4-D (Tordon 101)	8	1966	0	53	15	16	12	0	0	1	4
		1967	1	0	0	91	5	0	0	3	0
		1968	0	0	0	90	6	0	0	4	0
	16	1966	0	61	13	12	12	0	0	2	0
		1967	3	0	0	95	0	0	0	2	0
		1968	0	0	0	94	0	1	0	5	0
	32	1966	0	61	9	10	12	3	5	0	0
		1967	10	0	0	90	0	0	0	0	0
		1968	3	0	0	95	2	0	0	0	0

1 - Sonchus arvensis 2 - Cirsium arvense 3 - Hordeum jubatum 4 - Taraxacum officinale
5 - Chenopodium salinum 6 - Potentilla anserina 7 - Juncus balticus 8 - Trifolium pratense.

(Tables 15, 16) since in our study they enabled foxtail barley to almost completely replace Canada thistle and perennial sow thistle within a year and to provide a dense cover of vegetation of medium height. The general adaptability of this species in wet saline sites is well known (63).

An incidental field observation pertinent to natural succession and vegetation changes involving foxtail barley also seems appropriate here. One part of a large untreated area about one hundred yards from the treated plots discussed above, had in 1967, a cover of more than 90% of Canada thistle. During 1968 this local infestation had become reduced to about 40% of the cover. Foxtail barley and blue grasses became dominant in this particular area in a short period of time without assistance from herbicides.

3. Aircraft and mist blower applications of herbicide for control of thistles

Results from aircraft applications of 2,4-D at 8 oz and 2 lb/A in one gal/A diesel fuel to 60' x 750' strips of weed infested lakeshore were unsatisfactory in both 1966 and 1967. This was probably largely attributable to the fact that only a narrow experimental strip was the target (fig. 9) and a wind of up to 15 m.p.h. in 1966 and gusts to 5 m.p.h. in 1967 occurred during the spray operation. All the indicator plants to 400 feet downwind were severely damaged by the spray drift during 1966. There were no indicator plants beyond 400 feet. Injury from drift was evident about 30 feet upwind from the margins of the sprayed strips. Effects on the thistles sprayed in 1966 were patchy and not pronounced and were not detectable during the spring of 1967. In 1967 downwind drift occurred for more than 125 feet (fig. 10). Parts of the designated spray area and a few other patches considerably beyond it were completely "top-killed" by the heavier 2,4-D treatment but other sections, presumably because of

Figure 9. Aircraft spraying thistle infested strip at Miquelon Lake. (July 20, 1967).

Figure 10. Effects of 2,4-D ethyl ester spray drift on indicator bean plants. Left - control. Centre - a plant which was located 60 feet downwind from mist blower sprayed thistles was not visibly affected by drift. Right - spray drift damaged plant after exposure at a distance of 150 feet from aircraft - sprayed strips.

swirling of the spray, were unaffected.

The mist blower applications which involved 4, 8, and 32 oz/A of 2,4-D and 0.1, 0.25 and 1 oz/A of picloram in 1.6 gal/A made under almost calm conditions were quite successful. Drift effects on potted indicator bean seedlings placed at 10' intervals downwind varied from less than 20 feet to 60 feet from plot-boundaries (Fig. 10). The 2 lb/A dosages of 2,4-D and 1 oz/A of picloram caused top killing of thistles.

The mist from air-blast spray, however, also drifts readily with wind and it seems likely that conventional boom and nozzle ground sprayers or a hose line with a good 'gun-jet' type of nozzle carefully manipulated and applying relatively high gallonages per acre would be most practical for work of this nature.

SUMMARY AND CONCLUSIONS

At Miquelon Lake and at Ellerslie 0.25 ounces per acre dosage of picloram herbicide applied to Canada thistle at the early bud stage and to perennial sow thistle at prebud stage prevented opening of flowers and seed set of these species. Eight ounces of 2,4-D ethyl ester/A was needed to achieve the same effect of flowering prevention in thistles as resulted from use of 0.25 ounces of picloram per acre. If spraying was left until the thistle's late bud stage the above mentioned dosages of either chemical had little or no apparent effect on flowering. For effective prevention of flowering and for top-killing at the late bud stage higher rates of picloram and 2,4-D namely 1.5 oz and 2 lb/A respectively were quite effective.

Both at Miquelon Lake and at Ellerslie, picloram was the most effective herbicide in killing the roots of Canada thistle and perennial sow thistle. At Miquelon Lake in the presence of competition from grasses there was no thistle reinfestation during two years after treatment of plots with dosages of picloram of 4 oz or more per acre. In no instance were the results from application of 1 lb/A of picloram significantly superior to those from applications of one-fourth that amount. Degree of thistle control did not appear to differ following late summer (August 17, 1966) or fall applications (September 15, 1966). Foxtail barley and other perennial grasses showed similar high tolerance to late summer and fall applications of picloram, dicamba and 2,4-D. These herbicides were considered in decreasing order of effectiveness against the thistles to be picloram > dicamba > 2,4-D.

At Ellerslie where there was only rather limited competition of native vegetation, over 95% control of Canada thistle was obtained with treatments involving mowing at flowering stage, spraying with picloram

at a dosage of four ounces per acre when regrowth reached a height of 6-7" about a month later and followed by retreatment with 2 oz/A of the same herbicide after another mowing a year later. Results from such treatments were superior to results from spraying comparable single dosages of picloram on unmowed thistles at flowering time or from equally divided dosages of these herbicides one at flowering time and one about a month later in the fall. The same generalization applies to the results with 2,4-D except that with 2,4-D the results of application of a single dosage at flowering stage of the thistles (1968) were inferior to the results from applications of two equal dosages totalling the same amount, one half applied at flowering stage, the other half, a month later.

Ground sprayer techniques of application of herbicides were superior to aircraft applications under the conditions of the experiments at Miquelon Lake involving restricted target areas.

All dosages of herbicides that were effective against the vegetative top growth of thistles apparently resulted in reduction of percentage cover of broad-leaved plants, associated with an increase in grasses. The foxtail barley, baltic rush and other monocotyledonous plants appeared resistant to picloram at dosages large enough to kill the weeds. In some of the plots treated with high dosages of picloram (1 lb/A) or dicamba (1.5 lb/A), there was some stunting and leaf twisting of foxtail barley during part of summer of 1967, the year after treatment but such effects were no longer visible in 1968. Where foxtail barley is the dominant native cover, as at Miquelon Lake, the grass would gradually take over from the thistles as noted in trials in which one ounce of picloram per acre resulted in more than 90% control of dense Canada thistle and perennial sow thistle regrowth within a

year after the herbicide treatments. Thus the results show that either of two procedures can be used for effective results on Canada thistle and perennial sow thistle at Miquelon Lake.

One procedure involves prevention of flowering of thistles but retains them in a vegetative state until natural succession may result in the disappearance of these invaders of disturbed sites. The other procedure involves deliberate eradication of the thistles over a short period of time causing them to be replaced more rapidly than they would otherwise be, by native vegetation, in this case predominantly foxtail barley. From the agricultural standpoint this latter course of action would be the more attractive since it would require fewer repetitions of the spray application. Which of the alternative procedures would be best as a general recommendation in the interests of various forms of wildlife over the long run is very difficult to say since there are so many unknowns and potential subjective considerations involved from place to place and time to time.

In any event the problem from the general wildlife management standpoint seems to be one of rather limited proportions in view of the usual absence of thistles from stabilized native vegetation habitats. With regard to the specific farmland lakeshore site type in our experiments, eradication of the thistles and their replacement by the naturally dominant foxtail barley there seems to pose no obvious threat to current wildlife and particularly ducks. For the most part they appear to avoid nesting anywhere along the mainland lakeshore and seem to have left such habitat because of a strong preference for the relative solitude and safety of island nesting sites at Miquelon Lake (16).

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APPENDIX

Table 1 Details of chemicals used

Common name	Chemical name	Source
Picloram	Potassium salt of 4-amino 3,5,6-trichloropicolinic acid.	Dow Chemical of Canada, Ltd., Sarnia, Ont.
Tordon 101	Mixture of 20% picloram and 80% of 2,4-D present as amine formulations.	Dow.
Dicamba	2-methoxy-3,6-dichlorobenzoic acid.	Velsicol Chemical Corporation, 330 East Grand Avenue, Chicago 11, Illinois
2,4-D ester	Ethyl ester of 2,4-dichlorophenoxyacetic acid	Amchem Products, Inc. Ambler, Pa.
Atlox 210 (Surfactant)	A non-ionic blended product containing polysorbate, mono- and diglycerides, butylated hydroxyanisole, butylated hydroxytoluene and propyl glycol in a water-isopropanol medium	Atlas Chemical Industries, Inc., Wilmington, Delaware.

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